Calculation of the Cross-sectional Areas of Circuit Live Conductors

MOTOR CIRCUITS SUBJECT TO FREQUENT STOPPING AND STARTING

Regulations requires that where a motor is intended for intermittent duty and for frequent stopping and starting, account shall be taken of any cumulative effects of the starting periods upon the temperature rise of the equipment of the circuit. That equipment, of course, includes the cables feeding the motor.
When motors are regularly restarted soon after they have been stopped the cables supplying the motor may not have time to cool to close to the ambient temperature, this time being anything from 20 minutes or so to several hours depending on their size and method of installation.
Furthermore starting currents (for direct-on-line starting) can be between 5 and 8 times the full load current.
The calculation of any accurate factor to take account of frequent stopping and starting is complex and requires that information is provided on:

(a) the actual magnitude of the starting current
(b) the duration of, and rate of decay, of the starting current
(c) the full load current
(d) the first choice cable size to calculate its time constant
(e) the time intervals between stopping and starting.
It is suggested that the cable cross-sectional area is chosen on the basis of its current-carrying capacity being **1.4** times the full load current.

Example 1

A 10 hp 240 V single-phase motor is subject to frequent stopping and starting. The cable supplying the motor via a direct-on-line starter is two core, non-armoured cable having 85°C rubber insulation and copper conductors, clipped direct. If the ambient temperature is 50°C what should be the conductor cross-sectional area?

Answer

As 1 hp = 746 watts the full load current is:

$$\frac{10 \times 746}{240}\ \text{A} = 31.1\ \text{A}$$

The conductor current-carrying capacity should therefore be at least

1.4 x 31.1A= 43:5A.

As the ambient temperature is 50°C, from Table (3-18) (assuming the circuit overcurrent protective device is other than a BS 3036 semienclosed fuse) Ca is found to be 0.82.

The cross-sectional area of the conductor should therefore have Ia of at least 43.5/0.82 A= 53 A.

From Table (3-6) Column 6 (Method C) it is found that the minimum conductor cross-sectional area to use is 6 mm2 having I_{ta} = 58 A.

Due account has to be taken of the motor efficiency and motor power factor where these are known.

Example 2

A 415 V three-phase motor has a rating of 15 kW at a power factor of 0.8 lagging, the efficiency being 90%. If this motor is subject to frequent stopping and starting and it is intended to use a multicore armoured 70°C pvc-insulated cable having copper conductors, installed in free air, what should be their crosssectional area when ta = 35°C?

Answer

The full load current of the motor is:

$$\frac{15 \times 1000}{0.8 \times 0.9 \times \sqrt{3} \times 415}\ \text{A} = 29\ \text{A (per phase)}$$

The conductor current-carrying capacity should therefore be at least

1.4 x 29 A = 40:6A.

As the ambient temperature is 35°C, from Table (3-18) (assuming the circuit overcurrent protection device is other than a semi-enclosed fuse to BS 3036) Ca is found to be 0.94.

The cross-sectional area of the conductors should therefore have I_{ta} of at least 40.6/0.94 A=43.2 A.
From Table (3-7) Column 6 it is found that the minimum conductor cross-sectional area is 6 mm2 having I_{ta} = 41 A.

Note : in this example no mention is made of the nominal current rating of the overcurrent protective device for the motor circuit. The omission is deliberate because that device, in very many motor circuits, is providing short circuit protection only. Overload protection is provided by, for example, thermal overload relays in the motor starter. The nominal current rating of the overcurrent protective device in the motor circuit and its operating characteristics must be such as to provide adequate short circuit protection to the circuit conductors (i.e. give compliance with the adiabatic equation in Regulation 434–03–03) but not cause disconnection of the motor circuit because of high starting currents.

CIRCUITS FOR STAR-DELTA STARTING OF MOTORS

- With star-delta starters six conductors (two per phase) are required between the starter and the motor, the star or delta connections being made in the starter.
- During the running condition the current carried by each of the six cables is $1/\sqrt{3}$ times that of the supply cables to the starter (the connection being delta). If the motor cables are not grouped they require a current-carrying capacity 58% that of the supply cables.
- In practice it is far more likely that the motor cables are grouped together so that the grouping correction factor (Cg) for two circuits applies and the required current-carrying capacity for the motor cables becomes 72% that for the supply cables assuming the cables are either enclosed or bunched and clipped to a non-metallic surface.
- If a delta-connected motor is started direct-on-line the starting current may be between 5 and 8 times the full load current depending on the size and design of that motor. When star-delta starting is used the current taken from the supply is one third of that taken when starting direct on line. Hence the starting current in star may be between 1.67 and 2.67 times the full load current.

- During the starting period, because the star connection is used, the current in each of the motor cables equals that in the supply cables.Because the starting current is only carried for a short period advantage can be taken of the thermal inertia of the cables and the cables chosen on the basis of their running condition will be satisfactory for the starting current.

Example 3

A 415 V three-phase 20 kW motor has a power factor of 0.86 lagging and an efficiency of 90%. Star-delta starting is to be used. The supply cables to the starter are single-core 70°C pvc-insulated (copper conductors) in conduit. The motor cables from the starter are also single-core pvc insulated (copper conductors) and in another length of conduit. What is the minimum conductor cross-sectional area for both circuits if t_a = 30°C?

Answer

$$\text{The line current} = \frac{20 \times 1000}{\sqrt{3} \times 415 \times 0.86 \times 0.90}\ \text{A} = 35.9\ \text{A}$$

There are no correction factors to be applied.
From Table (3-5) Column 5, it is found that the minimum conductor cross-sectional area for the supply cables is 6 mm^2 having I_{ta} = 38 A.

For the cables from the starter to the motor, each cable carries

$$\frac{35.9}{\sqrt{3}}\ \text{A} = 20.7\ \text{A}$$

But now it is necessary to apply the grouping factor for two circuits which from Table (3-13) is 0.8.
Thus:

$$I_t = \frac{20.7}{0.8}\ \text{A} = 25.9\ \text{A}$$

Again from Table (3-5) Column 5 it is found that these cables can be of $4mm^2$ = 30 A.

As already stated, whilst during starting the cables between the motor cross-sectional area, having Ita and starter may be carrying a current of 35.9 x2.67 A (= 96 A), but the time the motor is held in star will generally be less than the time taken for these cables to reach the maximum permitted normal operating temperature.

Summary

Cable current carrying capacity calculations

1. Assessment of general characteristics
2. Determination of design current *I* b
3. Selection of protective device having nominal rating or setting *In*
4. Selection of appropriate rating factors
5. Calculation of tabulated conductor current *It*
6. Selection of suitable conductor size
7. Calculation of voltage drop
8. Evaluation of thermal risks to conductors.

Design current *I* b

This is defined as '*the magnitude of the current to be carried by a circuit in normal service* ' ,and is either determined directly from manufacturers' details or calculated using the following formulae:

Single phase:

$$I_b = \frac{P}{V} \quad \text{or} \quad \frac{P}{V \times \text{Eff}\% \times \text{PF}}$$

For three-phase :

$$I_b = \frac{P}{\sqrt{3} \times V_L} \quad \text{or} \quad \frac{P}{\sqrt{3} \times V_L \times \text{Eff\%} \times \text{PF}}$$

where:

P = power in watts
V = line to neutral voltage in volts
V_L = line to line voltage in volts
Eff% = efficiency
PF = power factor.

C_a	Factor for ambient air and ground temperature	(From IEC Regulations Tables (3-18)
C_g	Factor for groups of cables	(From IEE Regulations Table (3-13) to (3-17) and (3-19) to (3-22) for U/G cables
C_c	Factor:	
	if Semi-enc (re-wireable) fuse is used	(Factor is 0.725)
	if cable is buried direct in the ground	(Factor is 0.9)
	if both are involved	(Factor is 0.9 × 0.725 = 0.653)
C_i	Factor if cable is surrounded by thermally insulating material	(Ci Factor is 0.5)

Tabulated conductor current-carrying capacity I_t

$$I_t \geq \frac{I_n}{C_a \times C_g \times C_c \times C_i}$$

Note 1: Remember, only the relevant factors are to be used!

Note 2: In overload protection, the IEC and IEE Regulations permit the omission of such protection in certain circumstances; in these circumstances, I_n is replaced by I_b and the formula becomes:

$$I_n \geq \frac{I_b}{C_a \times C_g \times C_c \times C_i}$$

Voltage drop

Volt drop = mV/A/m

Table 1 Voltage drop values.

	Lighting	Power
	3%	5%
230 V single phase	6.9 V	11.5V
400 V three phase	12 V	20V

or fully translated with I_b for A and L (length in metres):

$$\text{Volt drop} = \frac{\text{mV} \times I_b \times \text{length}}{1000} \text{ volts}$$

For conductor sizes voltage drops Table (3-23) may be used .

Evaluation of thermal constraints

$$s = \frac{\sqrt{I^2 t}}{k}$$

where:

s = minimum csa of the conductor
I = fault current
t = disconnection time in seconds
k = Short – circuit factor